OPUS

Rotorua Lakes Council

Catchment 5 Stormwater Model Build and System Performance Report

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Stormwater Model Build and System Performance Report

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Contents

1 Introduction

Rotorua Lakes Council (RLC) has commissioned Opus International Consultants (Opus) to produce an assessment of the performance of Stormwater Catchment 5 within Rotorua township. As part of the project, a hydraulic stormwater model for the area has been built that will provide inputs to understanding the issues across the catchment and to developing some high level options for helping to resolve the identified and existing flooding issues affecting the main areas of interest between Selwyn and Larcy Roads.

The desired outcome of the model build is to develop a model that can be used to:

- Identify key flooding issues;
- Identify critical infrastructure and failure risks;
- Provide inputs for master planning and a means of identifying high level options that could help resolve the flooding issues for the desired Levels of Service (LoS);
- Assist operation and maintenance.

The development of the Stormwater Model and this report has involved the following phases of work:

Phase 1 - Data Review and Acquisition

Phase 2 - Model Build and Sensibility Checks

Phase 3 – Stormwater System Capacity Review and development of high level options

This report represents the deliverables for these three stages.

Opus will complete the remainder of the write up on the High level options development following discussion on the draft modelled solutions scheduled for week commencing 15th August 2016.

2 Catchment Description

2.1 Catchment Extent

Catchment 5 is one of Rotorua's main urban stormwater catchments covering an upstream rural area draining through the Urban area of Lynmore, adjacent to the lake. The urban catchment is the larger of the two at approximately 150 ha, and covers all the development in the Iles Road area through to Vaughan Road in the west. The urban catchment is predominantly residential development, although there is a commercial / industrial area between Te Ngae and Vaughan Roads. The rural catchment is 95 ha in size and is located to the east of the urban catchment. Figure 2-1 shows the location of the two catchments.

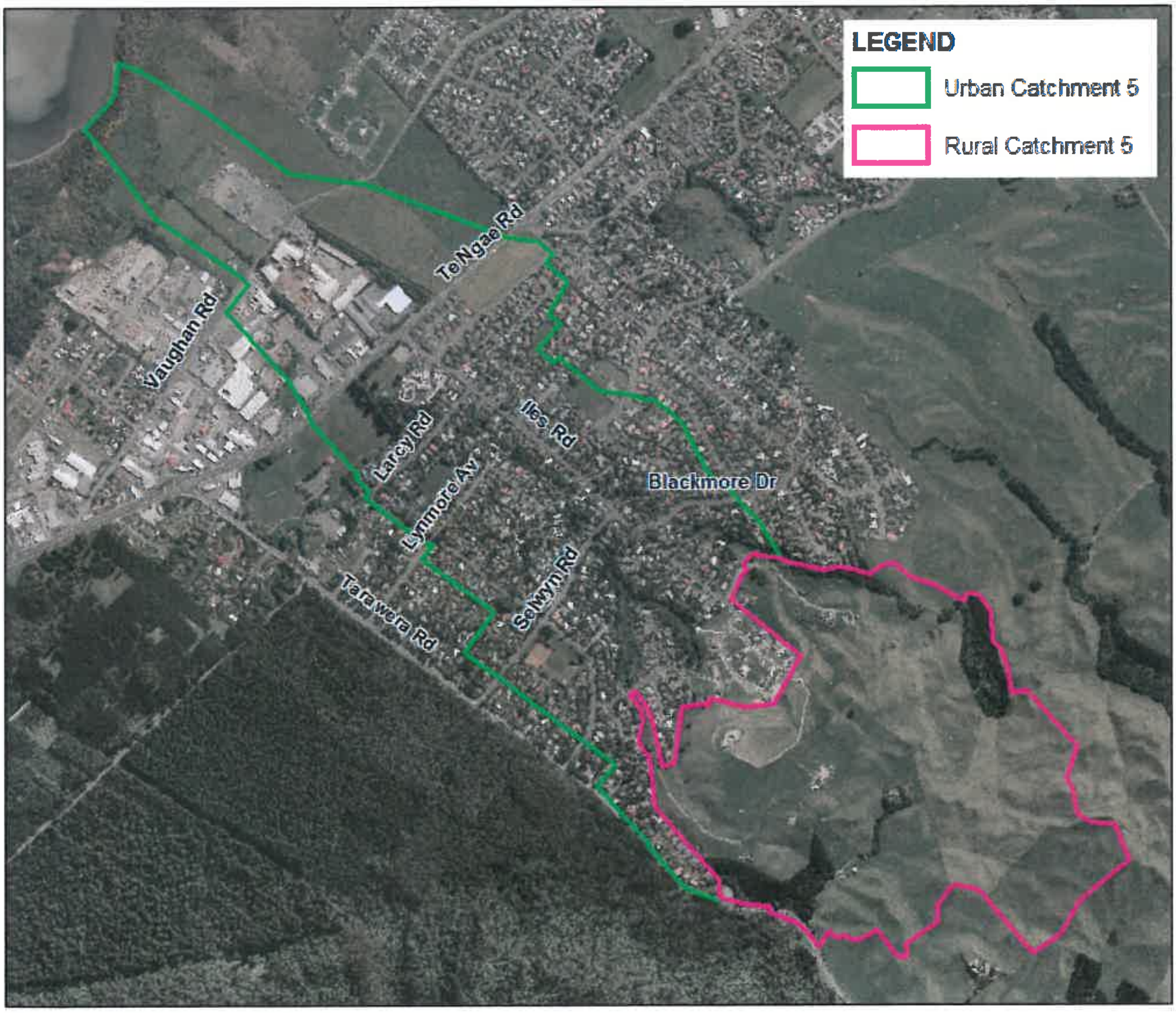

Figure 2-1: Catchment Extent

For simplicity, throughout the remainder of the report, "Catchment 5" will describe both the urban and rural catchments as one. The project is focussed on understanding the issues predominantly within the area between Selwyn and Larcy Roads as shown above.

2.2 Topography

The rural area in the southeast features undulating topography where the main watercourse originates and its elevation varies between 320 m and 500 mAD. The principal residential area of Lynmore is situated in the centre of the catchment at elevations between 367.2 m and 286.2 mAD. Elevation decreases towards the northwest of the catchment until it reaches the shores of Lake Rotorua at c. 279.65 mAD datum. Figure 2-2 shows the elevations across the catchment.

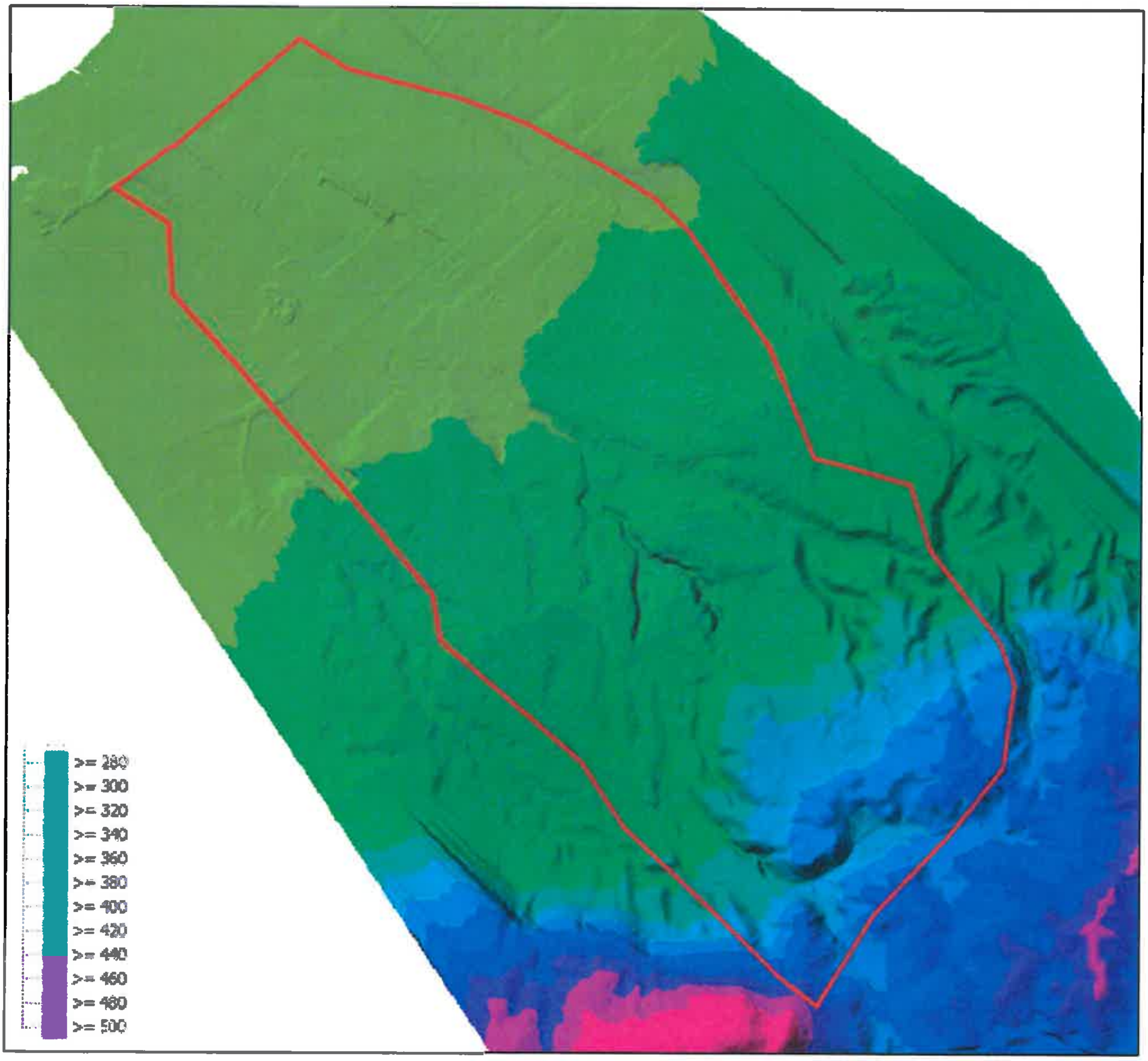

Figure 2-2: Catchment 5 Topography

2.3 Geology and Soils

The catchment is situated on the shores of Lake Rotorua where the geologic setting consists of late Quaternary alluvium, colluvium lake deposits, more commonly known as Zealandia Megasequence Terrestrial, and Shallow Marine Sedimentary Rocks. Soils in the area are generally formed from Tarawera Lapilli and rhyolitic tephra. Figure 2-3 shows the distribution of soil types across the catchment. As can be seen, the predominant soil type is F6.1a (Well-drained, low fertility soils from mid-age rhyolitic tephra).

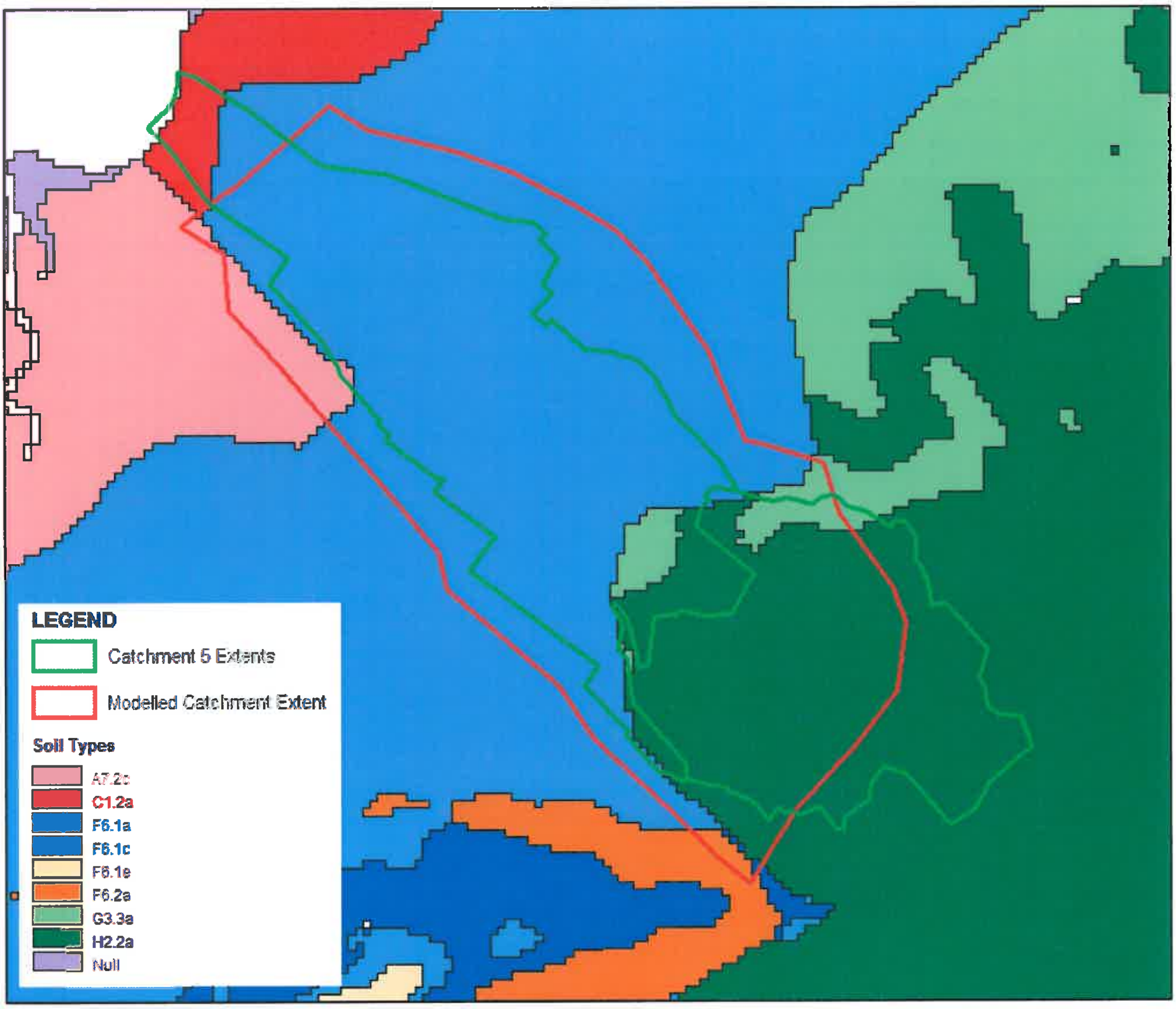

Figure 2-3: Soil Types (LRNZ, 2002)

Table 2-1 details the soil types within the model boundary.

Table 2-1: LENZ Soil Types (LRNZ, 2002)

Level III Classification	Landform	Soils	Level IV Characteristics
A7.2	Very gently undulating hills	Imperfectly drained soils of low fertility from rhyolitic tephra and alluvium, some peat and greywacke	c) lower winter temperatures, well-drained
C1.2	Gently undulating plains	Poorly-drained peat soils of low fertility with some alluvium	a) Warm temperatures, high solar radiation, slight annual water deficits
F6.1	Undulating hills	Well-drained, low fertility soils from mid-age rhyolitic	a) Warmer temperatures

Level III Classification	Landform	Soils	Level IV Characteristics
		tephra	c) Cooler temperatures
F6.2	Steep mountains	Well-drained, low fertility soils from mid age rhyolitic tephra	No subdivision at Level IV
G3.3	Very gently undulating flood plains	Recent, well-drained soils of low fertility from mixed alluvium	Warm temperatures, high solar radiation, moderate vapour pressure deficits, low annual water deficits
H2.2	Easy rolling hills	Recent, well-drained soils of moderate fertility from Tarawera lapilli and rhyolitic tephra	a) rolling hills, low fertility

2.4 Stormwater Network Overview

The stormwater system is shown in Figure 2-4 and consists of a combination of piped networks and natural and man-made waterways. The piped networks intercept and convey stormwater flows from the road corridor and property connections to the nearest stream channel or culvert. Stormwater collected from the road corridor consists of both road run-off and property discharges to the kerb and channel.

There are two primary drains in the catchment that converge into a single drain, but there are also other open channels in the network that connect into the drains or provide connections between different parts of the piped network.

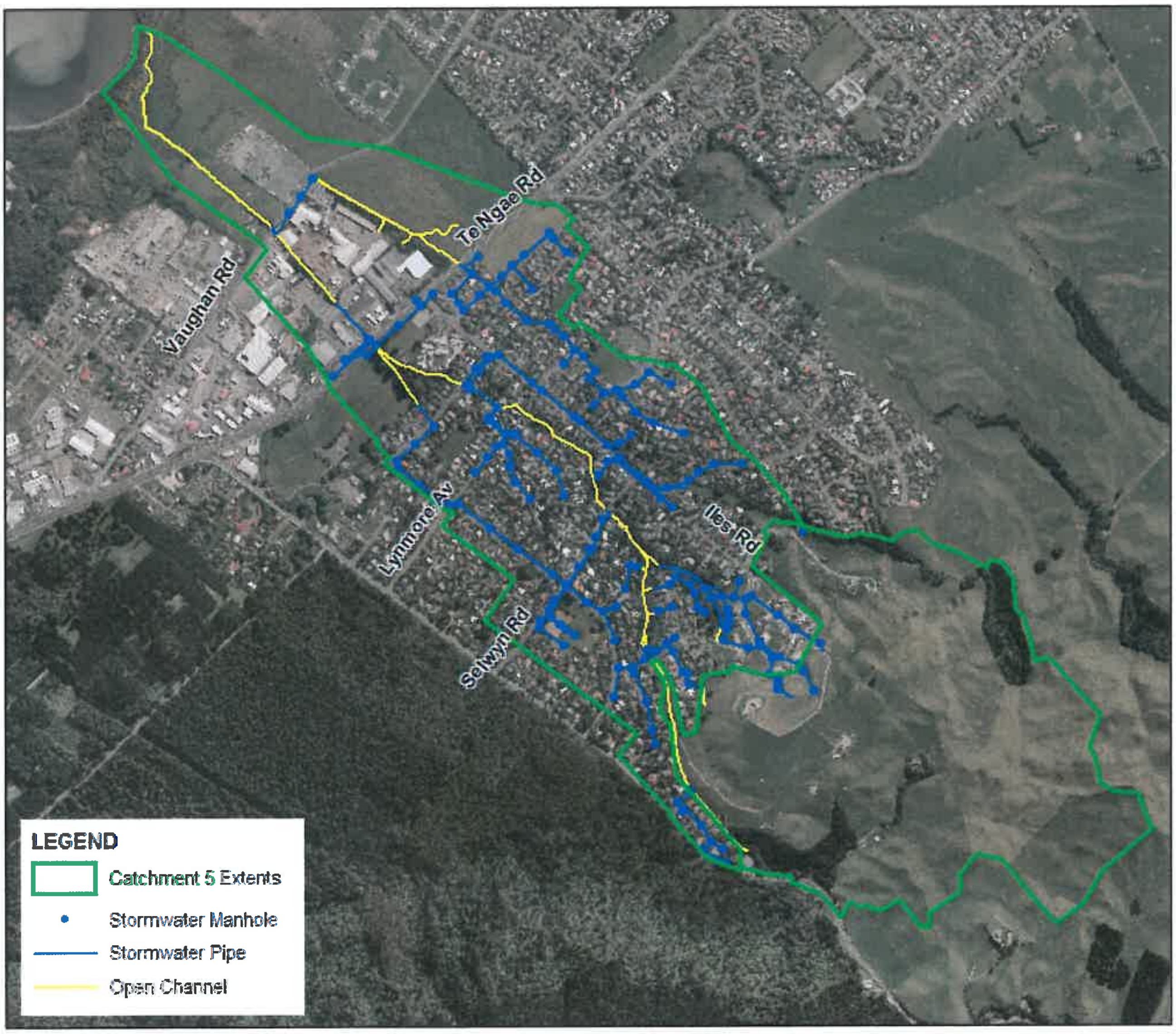

Figure 2-4: Catchment 5 Stormwater Network

Historic schemes creating solutions for flooding in the catchment have been undertaken resulting in areas designed for stormwater retention. Two notable areas have been engineered to release pressure on the downstream network: Iles Road detention pond and Link Road detention pond. Neil Hunt Park also serves as a natural detention pond but this effectively shares volume with catchment 6 to the southwest.

2.5 Land Use

The predominant land use throughout the catchment is of an urban nature, the majority of which is residentially zoned with a concentrated industrial area towards the shores of Lake Rotorua, in the north of the catchment. The catchment contains a significant area of rural land to the southeast encompassing approximately 40% of the catchment. Agricultural land uses are largely found in the southern rural areas but also cover small sections of land in the north. Land uses within the catchment are presented in Figure 2-5.

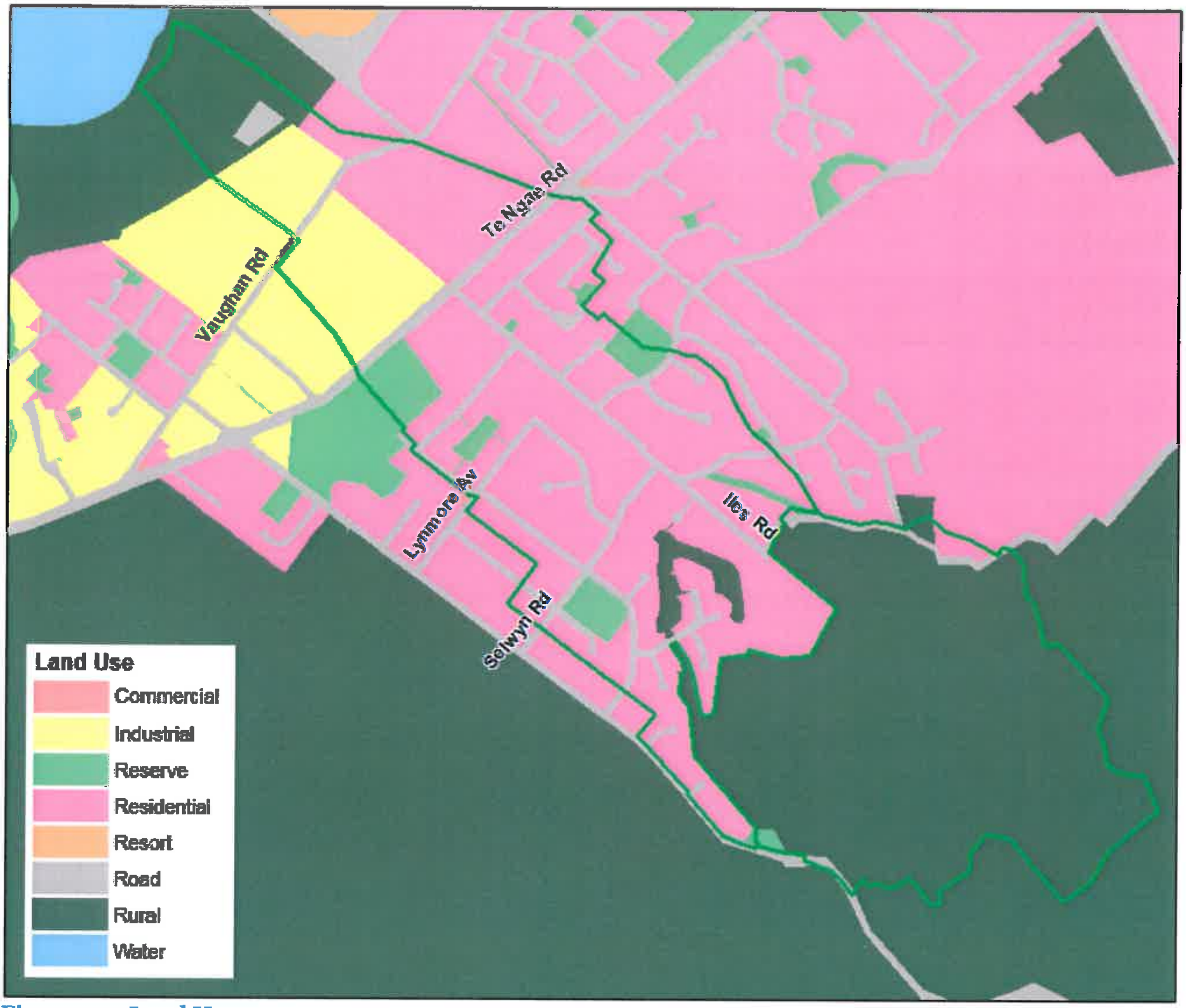

Figure 2-5: Land Use

2.6 Stormwater Issues

The predominant stormwater issue within the catchment, and the main driver for this investigation is the flooding experienced during large storm events. Both the eastern and western main drainage systems have previously become blocked by debris at the screened culverts under Te Ngae Road.

The open channel Selwyn-Larcy drain has been identified to be in poor structural condition, under capacity and frequently compromised. Stormwater cesspits on Selwyn Road are under capacity and a cesspit above Janet Place has previously blocked causing flooding. Towards the outskirts of the catchment a property on Hilton Road is also susceptible to flooding during heavy rainfall due to the natural topography causing excessive runoff over the property boundary.

3 Model Build

3.1 Hydraulic Model

RLC provided Opus with the stormwater layout in MapInfo TAB file format. This was imported into InfoWorks CS v16.5 as a 1D hydraulic model, where the data cleansing and 1D model build was undertaken.

When the 1D model was built using asset data, it was converted to a linked 1D-2D hydraulic model within InfoWorks ICM v6.5.2.

The coordinate system used was the New Zealand Geodetic Datum 2000 (NZGD2000) using the New Zealand Transverse Mercator (NZTM) projection. Levels are in terms of the Moturiki Mean Sea Level Datum 1953.

3.2 Asset Data

Asset and survey data required for development of the hydraulic model was collated from the following sources:

- RLC
  - GIS data;
  - DTM ground level information;
  - Aerial imagery;
  - As-built data;
- SurveyOne Limited
  - Site inspections;
  - Level surveys for selected manholes and cross sectional surveys of all open channels.

Table 3-1 lists the flags that have been used to identify the various data sources in the model.

Table 3-1: Data Flags Used

Flag	Description
#A	Asset Data
#D	System Default
AS	Data assumed based on engineering judgement
DU	Dummy parameter
HY	Hydraulic calculation
IF	Data inferred by InfoWorks automated process
L3	Inferred from 1m LiDAR
SD	Survey data
UC	Data from as-built data

3.2.1 Survey

Key infrastructure was surveyed by SurveyOne Limited in April-May 2016. The following data was collected:

- Incoming and outgoing pipe diameters and levels at important locations along the two primary drains;
- Inlet and outlet levels on open channels;
- Multiple cross sections along culverts and open channels

3.2.2 Nodes

The nodes are named as per the original GIS dataset provided by RLC. Few additional nodes were added to the model and, in general, nodes were only added to model complex structures such as the energy dissipation structure south of Walford Drive. Dummy nodes with a sole purpose of allowing structures to be modelled were named "DUM1_*NodeID*".

Flood types used in the model are summarised in Table 3-2.

Table 3-2: Flood types used to represent point assets

ICM Flood Type	Objects	Description
Sealed	Junctions	Water levels can rise indefinitely, pressurising the system.
2D	Manholes	Stormwater can flow to and from the 2D surface. The weir equation is used to control flow.
2D Outfall	Outfall 2D	Used at the downstream ends of small networks that discharge into a stream and for inlets and outlets to sections of culvert outside the river reaches. Flow exiting these outfalls flows onto the 2D mesh.
Outfall	Outfall	Stormwater is lost from the system - used at the end of the stormwater system.

All manhole data was calculated using the InfoWorks ICM defaults, including the node chamber area.

Figure 3-1 shows how this is calculated.

$$A = \frac{\pi}{4} \times (W + 0.762)^2$$

where:
A = default area
W = width of widest link incoming or outgoing

Figure 3-1: Calculation of chamber area in ICM (Innovyze, 2014)

3.2.2.1 Sumps (Catchpits)

Sumps have been removed from the model as per the agreed brief.

3.2.2.2 Soakholes

There are no known soakholes in the network. There may be some private on-site soakage, however no initial losses to account for these storage devices has been included in the model.

3.2.3 Pipes

Approximately 22% (or 56 pipes) in the RLC GIS dataset were missing an upstream, downstream or both invert levels. 15 pipes with missing inverts were removed from the model because they were subsoil drainage pipes.

The manhole survey provided invert levels for approximately 5% of the missing data points and the remaining levels were inferred either directly from their connecting manhole or by straight line interpolation. The interpolated results were then checked to ensure that the long section looked sensible when compared to the ground level. Outlet pipes were assumed to have their invert level at the ground level at the point of outfall based on DTM or survey.

In some instances it was necessary to use engineering judgement to set invert levels for terminal manholes on a pipeline or for pipes where the interpolation tool put the pipeline above ground. In general, we assumed a minimum pipe cover based on the levels of surrounding manholes and DTM data, unless this was deemed inappropriate.

Surface friction is applied to the piped network using typical Colebrook-White roughness coefficients depending on pipe material (range: 0.6-7).

Transitional head losses at the manholes have been inferred in ICM and applied to the pipes. The transitional head losses are based on the manhole approach and exit angles, pipe grade and approach velocity. The "Normal" head loss curve was used which is appropriate for well-constructed manholes.

Pipe gradients were calculated using InfoWorks ICM. Catchment gradient caused steep pipe gradients, therefore, the headlosses of any pipes with a gradient >10% were set to "None".

Service connections have been excluded from the modelling.

3.2.4 Culverts

Turbulence losses associated with the entry and exit of known culverts between river reaches have been modelled using culvert inlet and outlet links. Detailed entry losses have been modelled using values provided within the Culvert Design Manual (CIRIA, 2010).

The Selwyn Road Culvert was modelled to include the change in dimensions through the culvert identified during the topographic survey. At the upstream face, the culvert is an 1800mm diameter concrete pipe and modelled thus.

The culvert outlet survey identified the asset to be a concrete arch with a width of 1800mm and a top height of 1000mm. Due to the software limitation, we have modelled this asset within InfoWorks to be an arch with a diameter of 1800mm and a height of 1200mm. We have added 200mm of silt to the invert of the arch to reflect the actual surveyed dimensions. A site walkover in early May 2016, identified this to be an appropriate representation given the visible sedimentation, shown on Figure 3-2.

Figure 3-2 – Downstream face of Selwyn Road Culvert showing significant siltation and reduction in available cross sectional area.

3.2.5 Open Channels

The Selwyn-Larcy drain is the main open channel in the catchment that forms part of the stormwater network. It is wooden lined for the final ~70m (Figure 3-3) and is frequently compromised by garden waste, resulting in regular clearing to allow it to function as designed. This was surveyed with multiple cross sections being taken along the length of the channel.

Figure 3-3: Selwyn-Larcy drain final wooden section (left) and poorly formed channel upstream of wooden section (right)

The cross section data was used to create river reaches that were then linked to the 2D surface via bank lines to permit lateral flow. The bank lines have been modelled using a discharge coefficient of 1 and a modular discharge of 0.7. Manning's roughness values have been applied based on the channel profiles shown in aerial photos. Many of the channels had a gravel or mud channel base and were surrounded by bank vegetation; however, some channel sections were engineered with wooden banks and a fine gravel base.

Smaller open channels in the catchment have either been modelled using cross-sections taken from the DTM data, or by simply using the 2D surface.

3.2.6 Dams and Detention Ponds

There have been two schemes within the catchment to reduce the impact of flooding; Iles Road detention pond and Link Road detention pond. Neil Hunt Park has also been identified to act as a detention pond during heavy rainfall. All three of these detention ponds were modelled using the 2D surface, which has been deemed to have adequate resolution to enable the correct volume of storage to be represented in these areas.

A structure downstream of Walford Drive culvert has been identified to dissipate hydraulic energy (Figure 3-4). It features a large concrete channel approximately 25m in length with three 300 diameter orifices at its terminus. Once the three orifices have reached capacity, flow spills over the terminus wall. This structure has been modelled using a selection of 1D objects due to its complexity.

Figure 3-4: Walford Drive energy dissipation structure inlet (left) and outlet (right)

Figure 3-5 shows survey photos of the screened culvert inlet at Te Ngae Road. There are two successive screens which discharge to two 1350 mm diameter pipes. This screen has previously become blocked with debris, compromising the system and flooding Neil Hunt Park and many of the surrounding roads. This is likely to have been the case during the 20th August 2014 flood event.

Figure 3-5: Inlet to Te Ngae Road screened culvert

3.2.7 Sub-catchments

Model sub-catchments were constructed in MapInfo. The sub-catchment boundaries align with either parcel boundaries or ground contours and were attributed to a node based on the ground contours and the road and reticulation layout. A GIS layer showing stormwater service connections was available for the catchment and this information was used to allocate sub-catchments in this area. Sub-catchments have also been digitised to include only one land use type, which are based on the zoning information supplied by RLC and an inspection of aerial imagery.

At this stage, it must be identified that all of the rain falling within each subcatchment is assumed to discharge to the network point at which the subcatchment is identified to flow to. This will likely over-estimate the contribution of flows within the stormwater network, as localised drainage system in-capacities across the network including sumps, kerb and channels all store and convey the flows.

3.2.8 2D Surface

A 2D mesh surface has been included in the model. It is based on the supplied DTM. The mesh has the following attributes:

- Min triangle - 5 m^2
- Max triangle - 100 m^2
- Surface roughness - 0.1
- Boundary condition – Normal

Buildings (identified from the available and supplied GIS files from RLC) have been digitised and included in the mesh as voids.

3.2.9 Surface Roughness

Table 3-3 shows the range of Manning's 'n' surface values for differing cover type based on standard industry guidance. Varying surface roughness values have generally focused around the main channels and detention ponds within the catchment.

Table 3-3: Typical 2D Manning's 'n' Roughness Values

Land Use	Manning's 'n' values
Urban	0.1
Rural	0.035
Channels	0.023 – 0.1
Detention ponds	0.03 – 0.05

For the RLC catchment 5, a standard Manning's 'n' surface roughness of 0.1 has been used. This value represents roughness values appropriate for industrial buildings and urban residential parcels, which make up the majority of the catchment.

3.3 Hydrological Model

The inbuilt SCS runoff model has been used to calculate runoff from the impervious and pervious surfaces respectively. This runoff model uses a runoff curve number (CN) to convert mass rainfall to mass runoff. The CN is based on soil characteristics, plant cover, extent of impervious areas, interception and surface storage. Determining CN numbers depends on catchment soil type and cover conditions, represented as hydrologic soil group, cover type, treatment, hydrologic condition and antecedent runoff condition.

3.3.1 Hydrologic soil group

SCS uses four soil group categories; A, B, C and D, which range from low to high runoff potential (USDA, 2007). RLC catchment 5 has dominant soil types of F6.1a and H2.2a (Figure 2-3), which are both characterised to have good drainage potential. All curve numbers were therefore chosen using hydrologic soil group A.

3.3.2 Cover type

Cover type was determined by undertaking a desktop assessment of aerial photography. From this assessment residential areas were deemed to dominate the 1D part of the catchment. To assign a CN value to these areas digitisation of a 12.2 ha residential area in the north of the catchment estimated 47.6% of the sample residential area as impervious. A CN value was applied to each sub-catchment using a corresponding value in the TR55 urban hydrology for small watersheds manual (USDA, 1986). Due to calculated percentage imperviousness not directly corresponding to a residential cover type, ¼ acre lot size (38% impervious) was chosen for residential sub-catchments. Assessment of residential areas outside the sample area ensured this value was applicable for the catchment.

Two other cover types are found within the catchment; commercial districts in the north were assigned to commercial and business and sub-catchments which cover Te Ngae Road were assigned to streets and roads.

The assigned sub-catchment cover types and their corresponding curve numbers are detailed in Table 3-4.

3.3.3 Treatment

Treatment was not applicable for Catchment 5 due to the lack of sub-catchments encompassing agricultural areas.

3.3.4 Hydrologic Condition

Hydrologic condition is accounted for during determination of cover type. Pervious urban areas are assumed to have good hydrologic condition, while impervious areas are assumed to have an imperviousness of 98% and be directly connected to the drainage system.

Table 3-4: Curve numbers for sub-catchments.

Cover description	Average percent impervious area	Curve Number
Paved parking lots, roofs, driveways etc.	98	98
Urban district: Commercial and business	85	89
Residential district: average	38	61

Cover description	Average percent impervious area	Curve Number
lot size ¼ acre		
Rural	0	30

3.3.5 Antecedent rainfall condition

All CN's are calculated for average antecedent rainfall conditions.

3.4 Rainfall – Validation Event

Rainfall data recorded at the Whakarewarewa rain gauge, situated on the southern side of Lake Rotorua approximately 2 km from the catchment, was used for model runs.

The event of interest occurred on 20/08/14 peaking at 09:10 with a recorded value of 84 mm/hr and a total depth of 23 mm. Model runs were initiated at 00:00 19/08/14 and run for three full days, terminating at 00:00 21/08/14. To account for seasonal losses during the event, evaporation was set at 1 mm/day. This period gave adequate time before and after the event to allow antecedent conditions to be accounted for and to gauge system response.

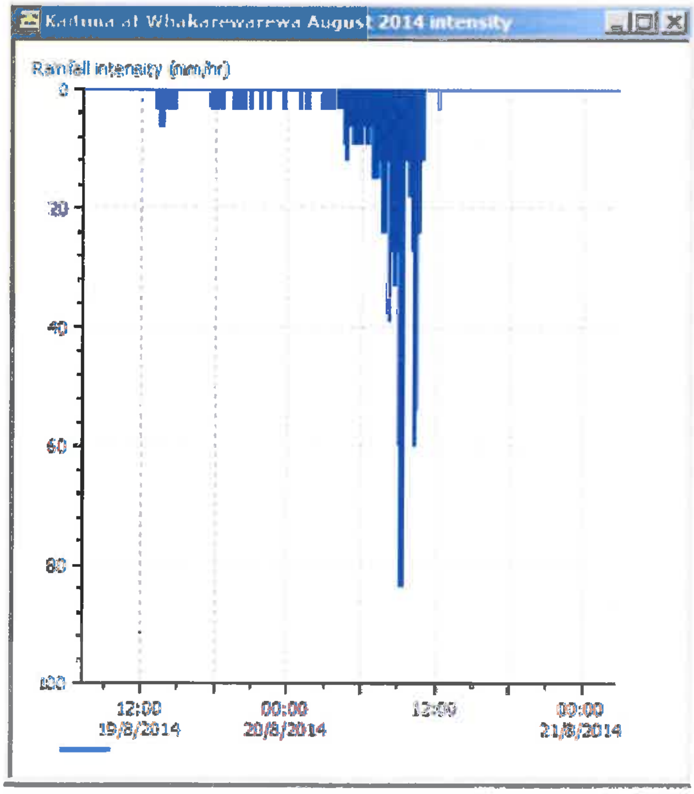

Figure 3-6: Observed rainfall between 19/08/14 and 21/08/14 used for model runs.

3.5 Boundary Conditions

The main stream, north of Vaughan Road, at the downstream extent of the model, where flows from the upper catchment converge into has been modelled with a boundary level of 281.18 mAD. This level was provided by RLC as the peak flood level for a 1 in 50 year ARI (2% AEP) storm event.

3.6 Summary of Modelled Objects

The following table summarises all the modelled objects.

Table 3-5: Modelled Objects

Modelled Object	Number
Number of Nodes	281
Number of Manholes Modelled	229
Number of Catch-pits Modelled	0
Number of Storage / Pond Nodes	0
Number of River Reach (Break) Nodes	28
Number of Outfall Nodes	1
Number of 2D Outfall Nodes	23
Number of Modelled Pipes	234
Total Modelled Pipe Length (m)	10,021
Pipe / Culvert Size (mm)	200 –5000
Number of River Reaches	25
Number of Subcatchments	118
Total Catchment Area (ha)	162
Average Sub-catchment Size (ha)	1.37

3.7 Data Issues

The following data issues were identified and resolved during the model build process:

- Approximately 17 % of the pipe invert levels were missing from the GIS dataset. Roughly 5% of the missing invert levels were collected in the survey and the remainder were interpolated, inferred, or assumed.

3.8 Assumptions

A number of assumptions were agreed with RLC in order to simplify the model build process. The impact of these assumptions on the model outputs will be discussed further.

3.8.1 Sumps

All of the sumps and sump leads have been removed from the model and sub-catchments have been attributed directly to manholes. This assumes that all runoff enters the pipe network and there is no capacity constraint on water entering the network. In reality, the sump density and sump lead capacities may constrain the peak flow into the network during high intensity events. Sumps are also typically lower than manholes, so will become the first overflow point when surcharged. The model will not directly show this but the lack of numerical correction undertaken on the modelled pipe network will create small amounts of additional storage.

3.8.2 Culvert Inlet Losses

Where possible, inlet types have been based on survey photos. However, there are a number of inlets that were not surveyed and so engineering judgement and aerial imagery has been used to model these inlets.

3.8.3 Pervious Runoff

All sub-catchment CN values have been assumed based on SCS CN curve guidance. The sample area used to determine imperviousness for residential sub-catchment CN values did not directly correspond to any residential average imperviousness. Cover descriptions have few options with broad requirements, reducing localised runoff accuracy for variable imperviousness in residential areas.

The model provides reasonable sub-catchment runoff values, suggesting the assumptions based on imperviousness are reasonable.

3.8.4 Baseflow

Baseflow has not been added to any sub-catchments but would be likely to be insignificant when compared to stormwater runoff.

3.8.5 Soakholes

Soakholes and soakpits have not been modelled.

4 Model Sensibility Checks

4.1 Sensibility Checks

The model will not be calibrated against observed river levels, flow or rainfall data under the current scope of works. Instead, sensibility checks were run to check that the model data is realistic and suitable for the intended purposes. The model outputs were checked against the following:

- Observed flooding for the August 2014 storm event
- Mass balance checks

4.2 Storm Event Validation

The model reliability has been tested by checking the predicted flooding against observed flooding for a recent storm event with known rainfall.

From Tuesday 19th through to Wednesday 20th August 2014, Rotorua experienced heavy rainfall causing flooding in many places, including within Catchment 5. Rainfall for the event has been taken from records for the Kaituna at Whakarewarewa rain gauge. This rain gauge is located approximately 2 km from Catchment 5 and due to the spatial variation in rainfall intensity, can only provide an approximate rainfall profile to input into the model.

Videos of the flood event were recorded by members of the public and show water depths at Te Ngae Road and Walford Drive. Observations were also recorded at Selwyn Road and Iles Road Detention Pond.

Stills from these videos showing the location and extent of flooding and correspondence containing the observations are provided in Appendix A.

The location and extent of observed and predicted flooding correspond well in places, but in other locations appears under predicted. This may be due to spatial variation in the rainfall, the interaction of other catchments with this catchment, or temporal capacity issues which are not now apparent.

The extent of blinding to the culvert inlet screen at Te Ngae Road during the event is unknown and it is recommended that sensitivity to screen blinding is considered in any further modelling.

Flood maps shown in Appendix B show the extent of the modelled flooding for the August 2014 event. These show a reasonable correlation against the areas identified to have historic issues and the evidence presented in Appendix A (photos and stills from videos of the event). Notable areas are discussed in more detail below.

There is some uncertainty between the timing between the photos and the model results. We have assumed that they occur around the peak of the event though it is possible that the degree of flooding could have been worse than shown in the photos.

4.2.1 Te Ngae Road and Neil Hunt Park

Figure 4-1 shows the model predicts extensive surface ponding within Neil Hunt Park and along the southeast side of Te Ngae Road, this gives a good match with Figure 8-1 and Figure 8-2. The Neil Hunt Park channel and Larcy Drain both overtop flooding the area around them.

Figure 4-1: Te Ngae Road and Neil Hunt Park

4.2.2 Selwyn Road Culvert

Figure 4-2 shows the model does not predict significant ponding around the Selwyn Road Culvert, whereas Figure 8-4 shows that the flood level was practically at the road level. In the model, the river reach and culvert are able to convey flow downstream with no significant hydraulic impedance. The 2D flooding shown in this area is mostly from overland flow through properties from 34 Hilton Road to 24 Selwyn Road.

The photo also shows that the catchment is quite bushy upstream of the culvert and it may be that the culvert was partially obstructed causing flows to back up and ultimately flood. However, since we have no evidence of this we have left the model as is to avoid 'force fitting' the model.

Figure 4-3 shows that the downstream velocities through the culvert exceed 2 m/s for just over 2 hours during the peak of the storm which will cause significant scour and can help to explain the erosion that occurred on the left bank at the culvert outlet during this event.

Figure 4-2: Selwyn Road Culvert

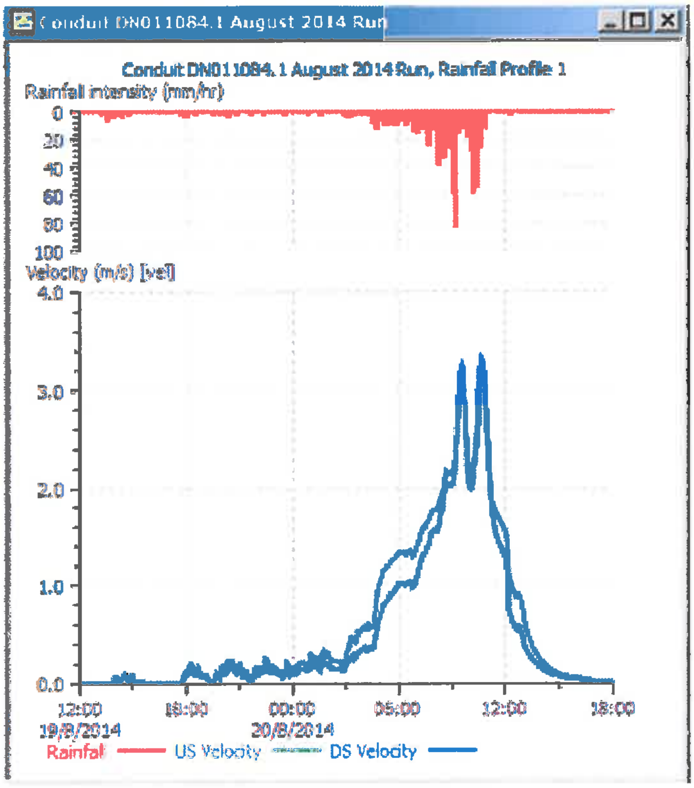

Figure 4-3: Selwyn Road Culvert Velocity

4.2.3 Walford Drive

Figure 4-4 shows the predicted flooding around Walford Drive, this gives a reasonable match with Figure 8-3. The model predicts relatively fast and shallow flooding; Figure 4-5 shows that the flow through here is typically 1 m^3/s for the main body of the storm though peaks around 3 m^3/s in response to the peaks in rainfall intensity.

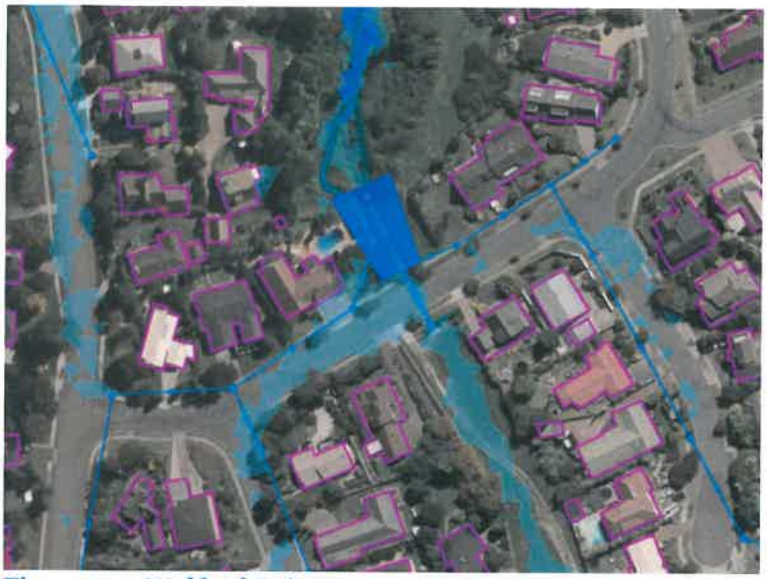

Figure 4-4: Walford Drive

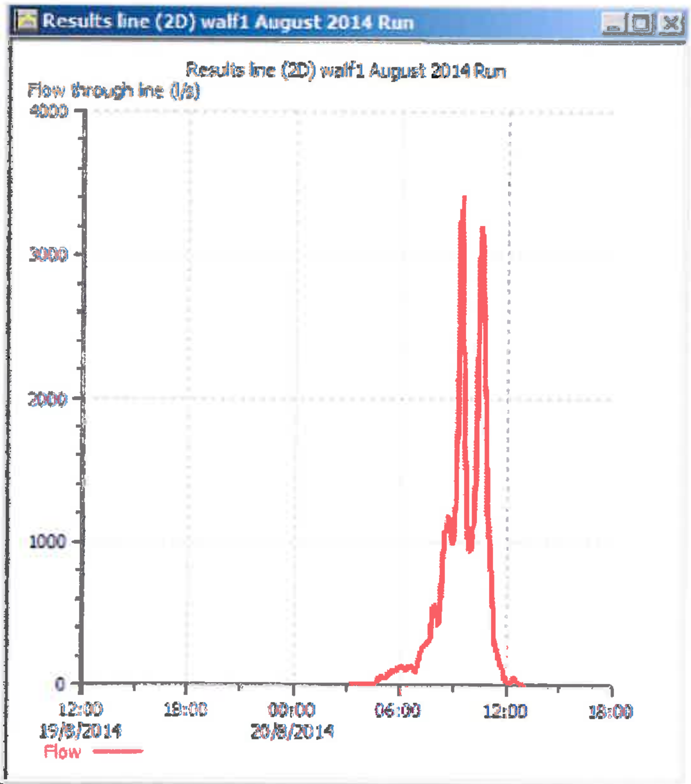

Figure 4-5: Flow in channel downstream of Walford Drive

4.3 Mass Balance Checks

Cumulative mass balance checks are automatically undertaken by ICM's software engine by default at each simulation time step. If the cumulative mass balance error exceeds 0.01 m^3 at any time step, the simulation is automatically terminated. Thereby, any completed simulation can be considered to have passed this check. Following the successful completion of the simulation, the simulation log file identifies the volume balance for each node within the network, and as a total for the whole simulation. The volume balances for the 24 hour duration nested storm simulations are shown in Table 4-1.

Table 4-1: Summary of % Volume Balance

Design Storm Event (AEP)	1D Volume Balance		2D Volume Balance	
	m^3	%	Mass Error Balance (%)	Total Mass Error (m3)
10%	1,088	0.17	0	0
2%	-20,939	-1.71	0	0

5 System Performance

System performance was assessed for both the 10% and 2% AEP 24 hour nested storms with climate change, see Figure 5-1.

All system performance maps can be found in Appendix B; these include flood depth, parcels with flood depths greater than 300mm, and flood hazard maps.

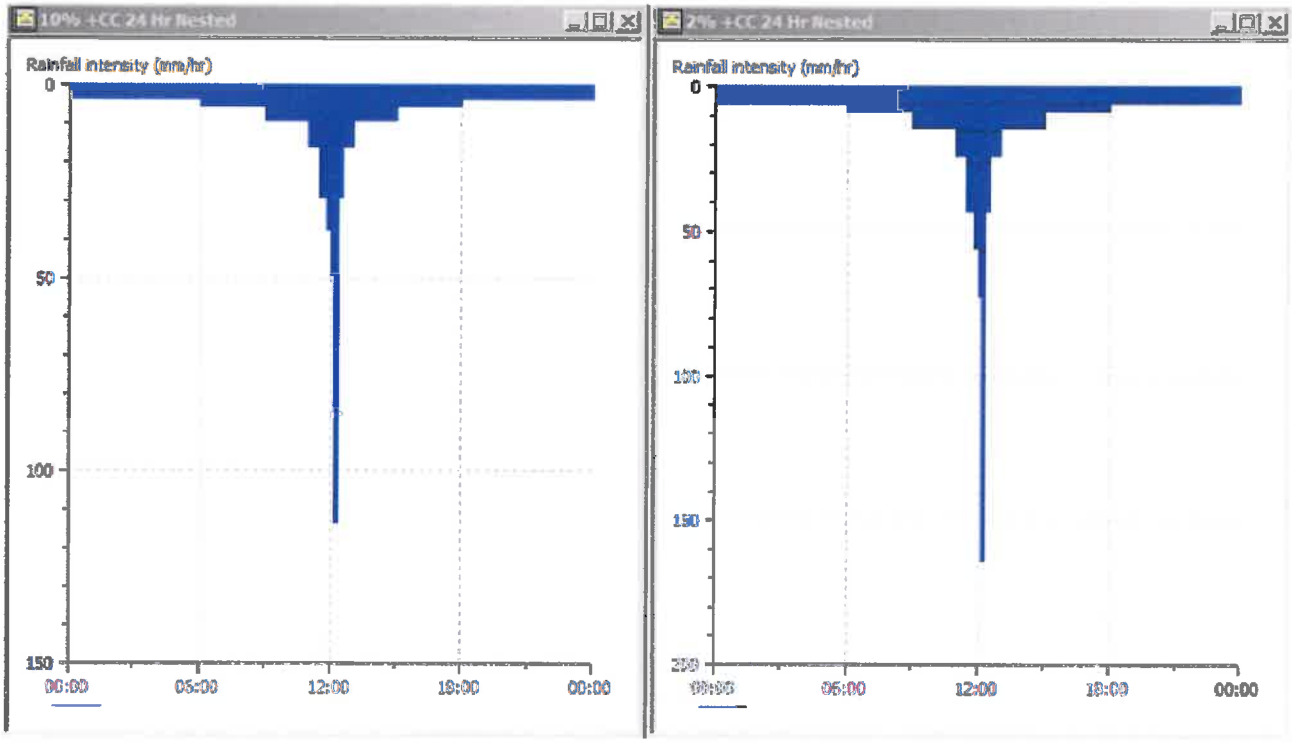

Figure 5-1: 24 hour nested storm with climate change (left 10% AEP, right 2% AEP)

5.1 General Observations

Overland flow due to undersized pipework is highlighted by the model as the key mode of flood risk. During the 10% AEP event for example, overland flow is running across Iles Road, through properties between Warwick Drive and Orchard Place and across Larcy Road. The worst flooding predicted is between Fairly Road and Larcy Road where flow breaks out of channel and flows through properties. This is due to the downstream pipework being undersized for the predicted flow.

The upstream end of the pipe is modelled as DN1200 which would have a capacity of around 4.4m³/s, whilst the peak flow predicted exceeds that by a significant margin.

Widespread flooding is also predicted along State Highway 30, at the school and through the park is a low lying area which ponds with stormwater. This is the culmination of flow into the area, headloss at the culvert entrance under SH30 and the low lying nature of the land.

Widespread flooding is also predicted in the downstream industrial area due to flow breaking out of bank at a low spot on Vaughan Road and upstream between Vaughan Road and SH30.

5.2 Flood Depths

Table 5-1 summarises the total ponding areas by depth of ponding excluding those areas that have been modelled as river reaches. Flood maps in Appendix B show these ponding locations spatially. Open channels modelled as river reaches were assumed to be greater than 300 mm deep.

Table 5-1: 2D ponding depths

Event	Ponding depth areas (ha)			
	≥ 50 mm	≥ 150 mm	≥ 300 mm	Total
10% AEP	20.8	9.7	5.8	36.3
2% AEP	25.8	13.8	11.5	51.1

5.3 Parcels with Ponding

Parcels that intersected with any ponding that was greater than 300 mm were identified, this excluded open channels modelled as river reaches unless there was out of bank flow causing significant ponding. The number of parcels with ponding greater than 300 mm are shown in Table 5-2. The locations of these parcels are shown in Appendix B together with the extent of ponding.

Table 5-2: Parcels with ponding greater than 300 mm

Event	Number of Parcels with ponding greater than 300 mm
10% AEP	275
2% AEP	358

5.4 Referable or Classifiable Dams

The figure and definitions below for a Referable or Classifiable Dam are taken from the Ministry of Business, Innovation & Employment Consultation document: "Keeping our dams safe: Proposed amendments to the Building (Dam Safety) Regulations 2008" (MBIE, August 2013).

Classifiable dam

A dam which has either:

- a height of 8 or more metres and holds 20,000 or more cubic metres volume of water or other fluid; or
- a height of 4 or more metres and holds 100,000 or more cubic metres volume of water or other fluid.

Referable dam

A dam which:

- has a height of 4 or more metres or holds 20,000 or more cubic metres volume of water or other fluid; and
- is not a classifiable dam.

TABLE 1: THRESHOLDS FOR CLASSIFIABLE, REFERABLE, AND LARGE DAMS

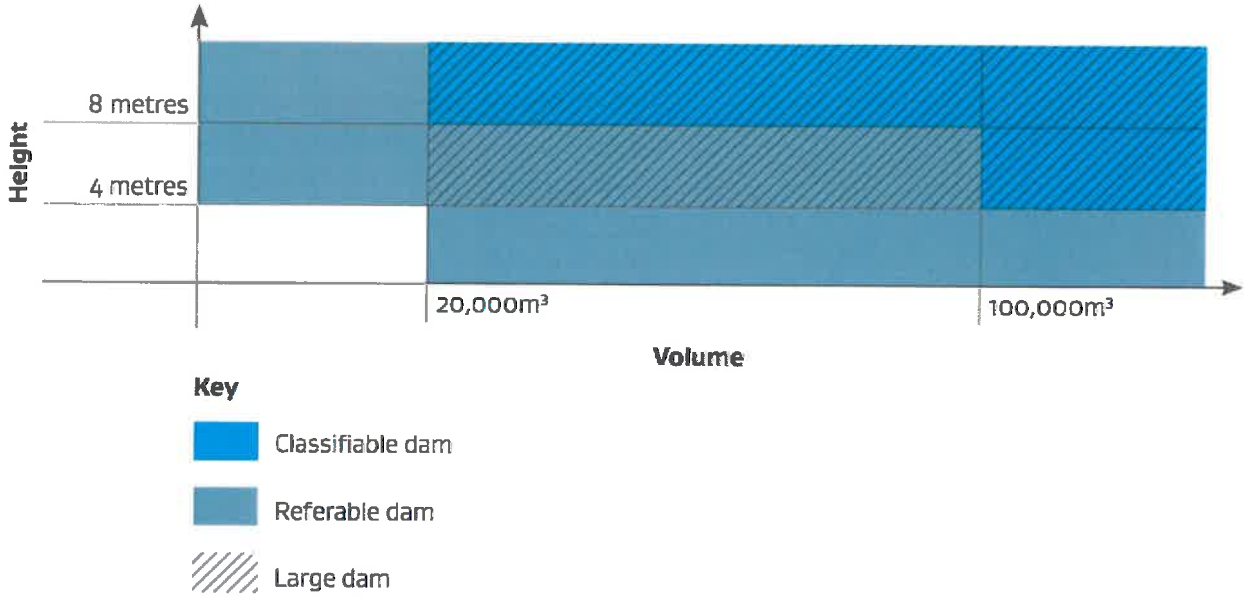

Figure 5-2: Thresholds for Classifiable, Referable, and Large Dams

Investigating areas of ponding for the 2% storm did not identify any referable or classifiable dams.

5.5 Flood Hazard

Flood hazard maps have been produced for emergency planning purposes (see Appendix B), and are intended to provide an indication of the severity of flooding during both the 10% and 2% AEP event. These maps utilise a Hazard Rating (HR) to quantify the flood risk to the public during such an event. The Hazard Rating calculated in ICM is based on the flood flow velocity, depth of flow, and a debris factor, according to the following formula:

$$HR = d \times (v + 0.5) + DF$$

Where:

d = depth of flooding (m)

v = velocity of flood waters (m/s)

DF = debris factor

The full methodology applied is described in "Supplementary Note on Flood Hazard Ratings and Thresholds for Development Planning and Control Purpose" (Surendran et. al. 2008)[1].

Table 5-3 defines the flood hazard ratings used in the emergency planning maps. The relationship between flood hazard rating, flow depth and velocity is illustrated in Figure 5-3.

River reaches were set to extreme hazard which is appropriate for an open channel in flood.

[1] *Surendran, S., Gibbs, G., Wade, S. and Udale-Clarke, H. May 2008. Supplementary Note on Flood Hazard Ratings and Thresholds for Development Planning and Control Purpose, Clarification of the Table 13.1 of FD2320/TR2 and Figure 3.2 of FD2321/TR1.*

Table 5-3: Flood Hazard Rating Criteria

Thresholds for Flood Hazard Rating	Degree of Flood Hazard	Flood Hazard Description
< 0.75	Low	Caution - flood zone with shallow flowing water or deep standing water
0.75 - 1.25	Moderate	Dangerous for some (i.e. children) - flood zone with deep (< 250 mm) or fast flowing water
1.25 - 2.0	Significant	Dangerous for most people - flood zone with deep (250 mm – 500 mm), fast flowing water
> 2.0	Extreme	Dangerous for all - flood zone with deep (500 mm or greater), fast flowing water

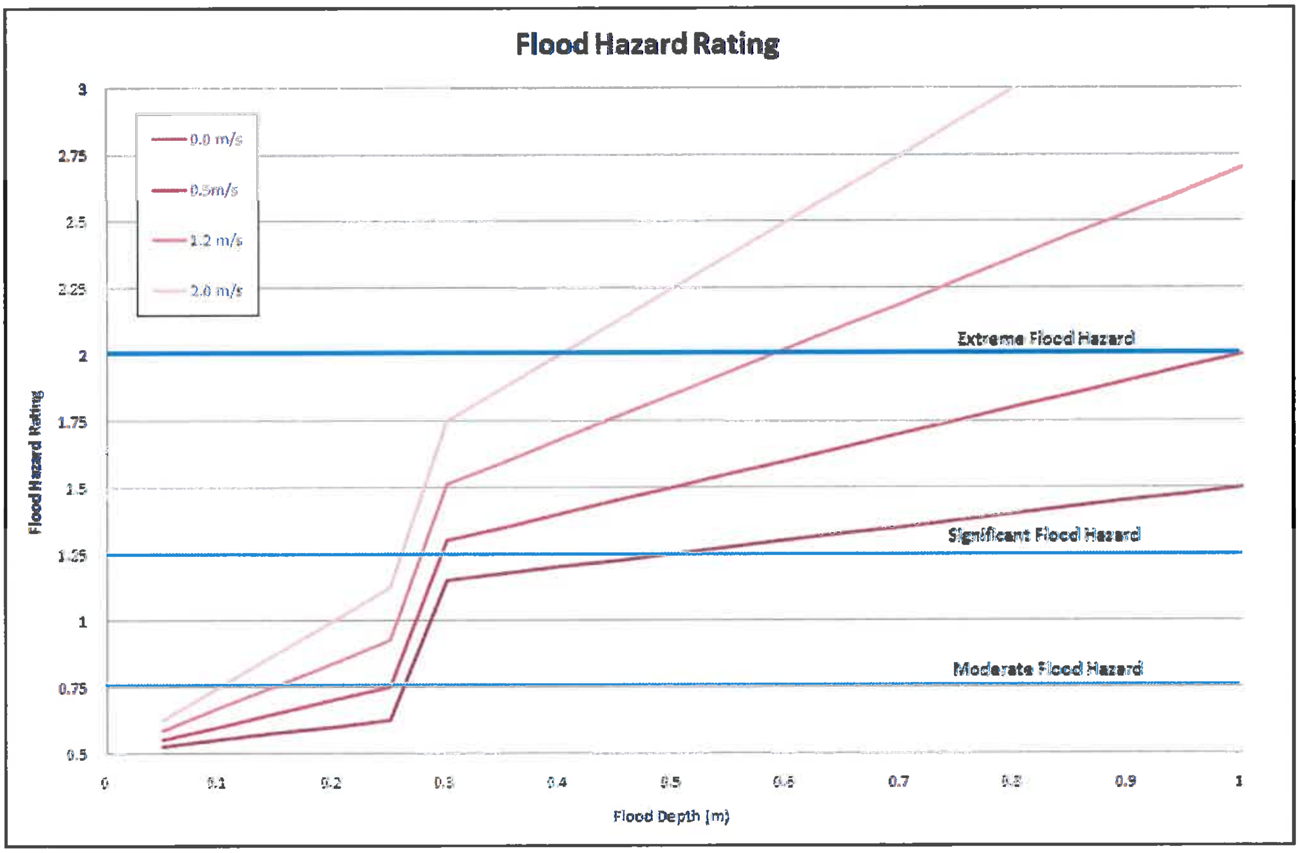

Figure 5-3: Flood Hazard Rating details

6 Model Confidence and Recommendations

6.1 Recommendations

The following extra additional model enhancement or investigation is recommended:

- **Investigate Iles Road detention pond** – The representation of the pond within the model is based on the LiDAR ground model and a set of as built plans which do not contain many dimensions. It is recommended that a full topographic survey is carried out to confirm details and the model updated accordingly.

In addition the following sensitivity analyses could be undertaken:

- **Screen Blinding** – Check impact of varying levels of screen blinding at Te Ngae Road.
- **Hydrology** – The infiltration rate applied to pervious areas could be set higher or lower;
- **Manhole Headloss** – Set the headloss curve to High instead of Normal;
- **Soakage** – Increase initial losses;
- **Roughness** – Surface roughness can be increased or decreased;
- **Boundary Conditions** – Check impact of varying lake levels on the catchment;

These analyses will indicate how sensitive the model results are to changes in the model parameters.

6.2 Model Confidence

Based on the quality of the survey data available to build the model and a generally good correlation between predicted and observed flooding, the model is thought to be the best tool available to provide inputs to the options assessment against the over-arching management plan level of service as identified within the Infrastructure Strategy 2015-2045.

The predicted flood extents for the 10% and 2% AEP nested storm design events are shown on the maps in Appendix B. It is considered that these extents are generally consistent with customer complaints and observed flooding.

However, the model results are likely to be highly dependent on factors such as antecedent rainfall i.e. catchment wetness. Further sensitivity analysis could also be used to confirm areas within the model where the results are largely independent of parameter changes. The model can be used in these areas with higher certainty for planning purposes and decision making.

Confidence in areas of the model with lower certainty could be targeted and improved at a later date by calibrating the model against recorded flow and rainfall data. This would provide greater confidence in the pervious, baseflow, soakage and hydraulic assumptions.

7 References

CIRIA. (2010). *Culvert Design Manual.*

Innovyze. (2014). *InfoWorks Help.*

MBIE. (August 2013). *Keeping our dams safe: Proposed amendments to the Building (Dam Safety) Regulations 2008. Consultation Document.*

Surendran, S., Gibbs, G., Wade, S., & Udale-Clarke, H. (May 2008). *Supplementary Note on Flood Hazard Ratings and Thresholds for Development Planning and Control Purpose, Clarification of the Table 13.1 of FD2320/TR2 and Figure 3.2 of FD2321/TR1.*

8 Appendices

Appendix A – August 2014 Event Photos & Modelled Flood Maps

Appendix B – System Performance Maps

Appendix A – August 2014 Event Photos

Figure 8-1: Still image from video of Te Ngae Road flooding, August 2014.

Figure 8-2: Still image from video of Te Ngae Road flooding, August 2014. Western drainage system showing the culvert inlet screen potentially overloaded and view of flooding extent in Neil Hunt Park.

Figure 8-3: Still image from video of Walford Drive flooding, August 2014

Figure 8-4: Red dot marking location of recorded flood level upstream of Selwyn Road culvert inlet. Flood mark recorded at 305.172 m above Moturiki datum.

Appendix B – System Performance Maps

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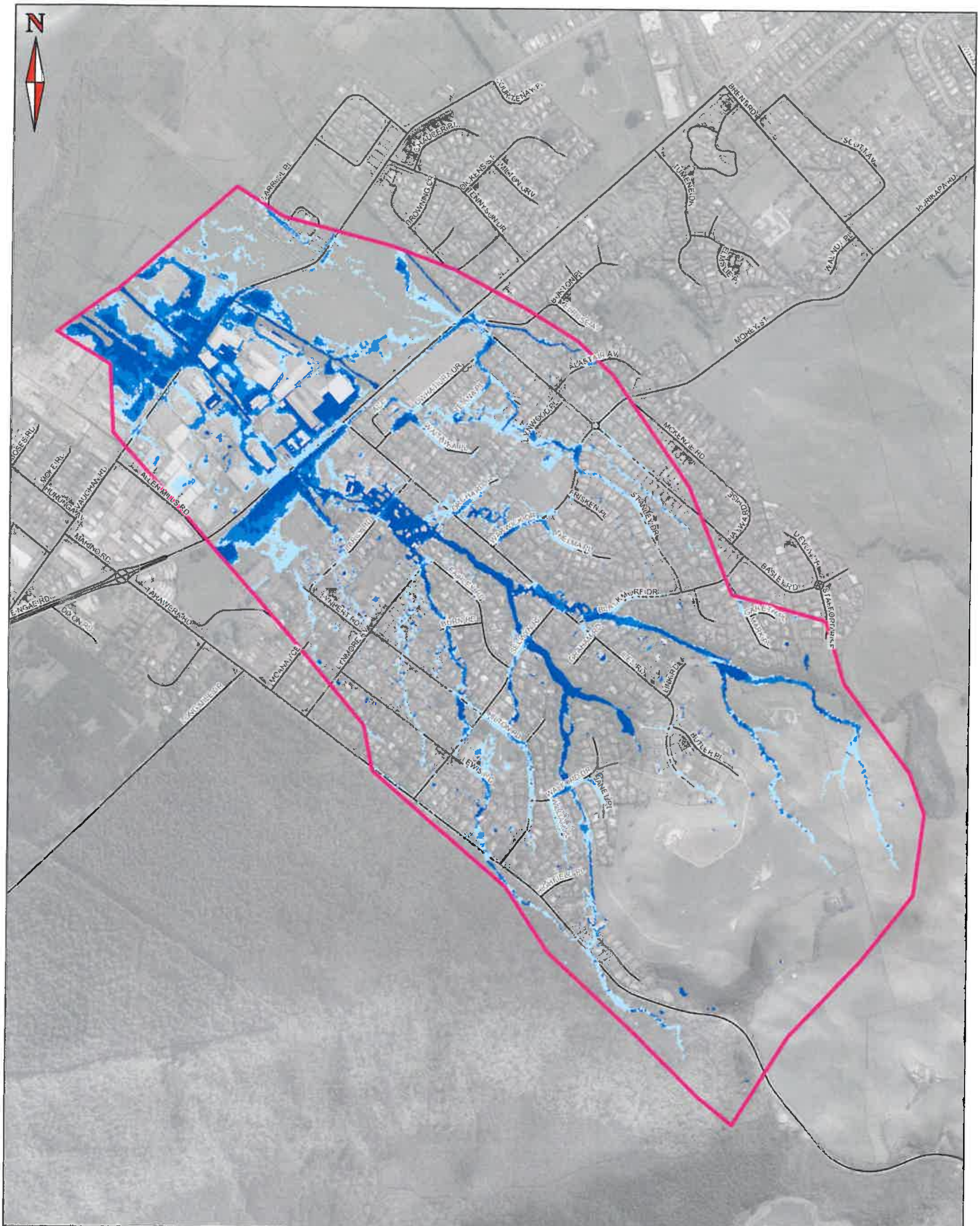


CONTAINS NZ TERRAIN RELIEF (TOPO50) DATA SOURCED FROM LINZ DATA SERVICE UNDER CREATIVE COMMONS ATTRIBUTION 3.0 NEW ZEALAND (CC BY 3.0 NZ)

Legend

Catchment Boundary

Parcel Boundaries

Roads

Flood Depth (m)

- > 0.3
- 0.15 to 0.3
- 0.05 to 0.15

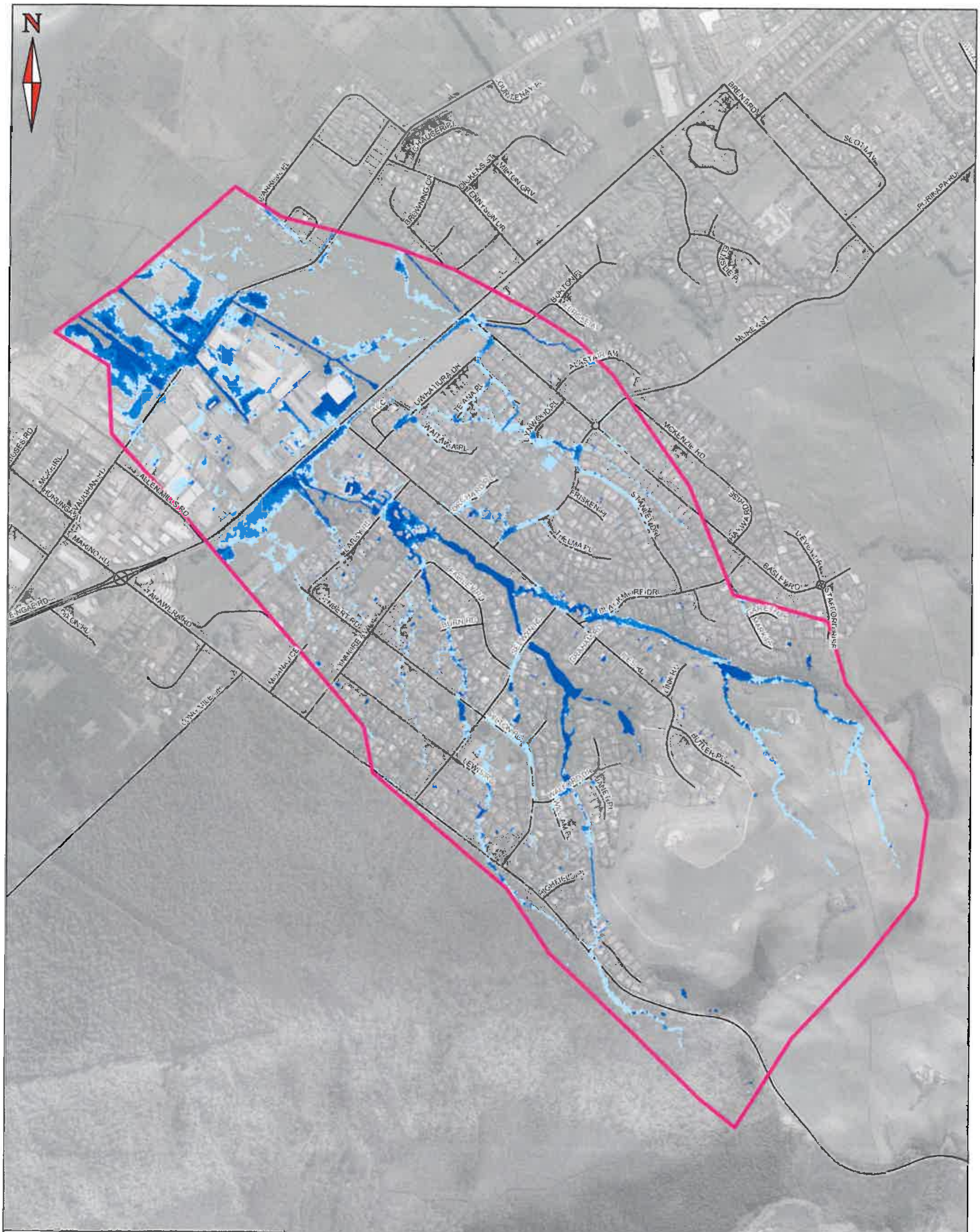
Original Sheet Size: A3 (V) Projection: NZTM

ROTORUA LAKES COUNCIL

OPUS

Opus International Consultants Limited
Christchurch Environmental Engineering
PO Box 1482
Christchurch 8140, New Zealand
+64 3 363 5400

PROJECT: Rotorua Lakes Council Catchment 5 Stormwater Modelling				
DRAWN: BJS	APPROVED: LAF	REV: R1	REV DATE: 04 Aug 2016	PLAN: 2% AEP Flood Depth Map
PROJECT NO.: 3-C1423.00	SCALE: 1:10,000 @ A3	PLAN NO: FD-02P	SHEET NO: 1 of 1	FILE REF



Legend

Catchment Boundary

Parcel Boundaries

Roads

Flood Depth (m)

> 0.3

0.15 to 0.3

0.05 to 0.15

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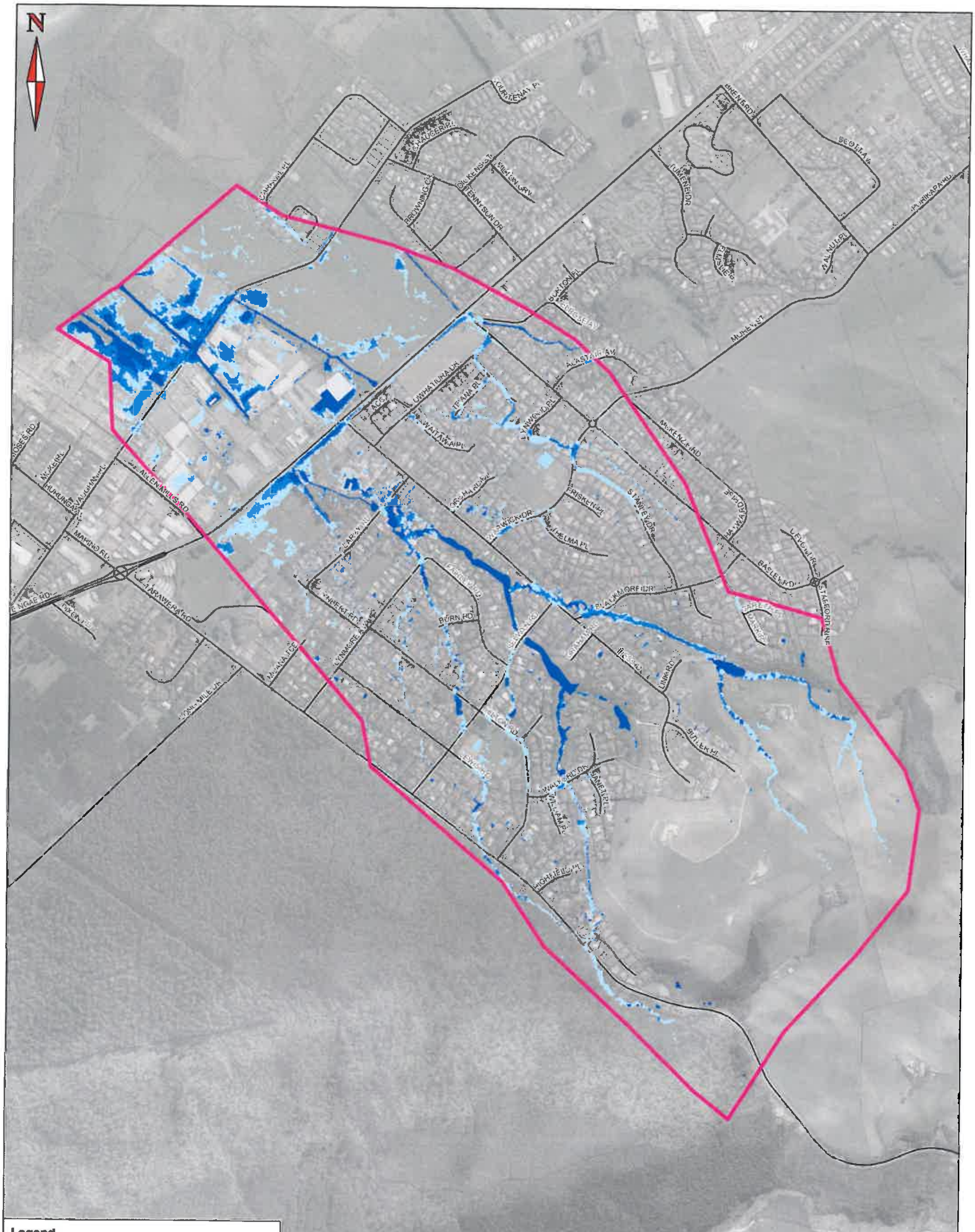
DRAWN BJS	APPROVED LAF	REV R1	REV DATE 04 Aug 2016	PLAN 10% AEP Flood Depth Map
PROJECT NO. 3-C1423.00	SCALE 1:10,000 @ A3	PLAN NO FD-10P	SHEET NO 1 of 1	FILE REF

Original Sheet Size: A3 (V) Projection: NZTM



Legend

- Catchment Boundary
- Parcel Boundaries
- Roads

Flood Depth (m)

- > 0.3
- 0.15 to 0.3
- 0.05 to 0.15

Original Sheet Size: A3 (V) Projection: NZTM

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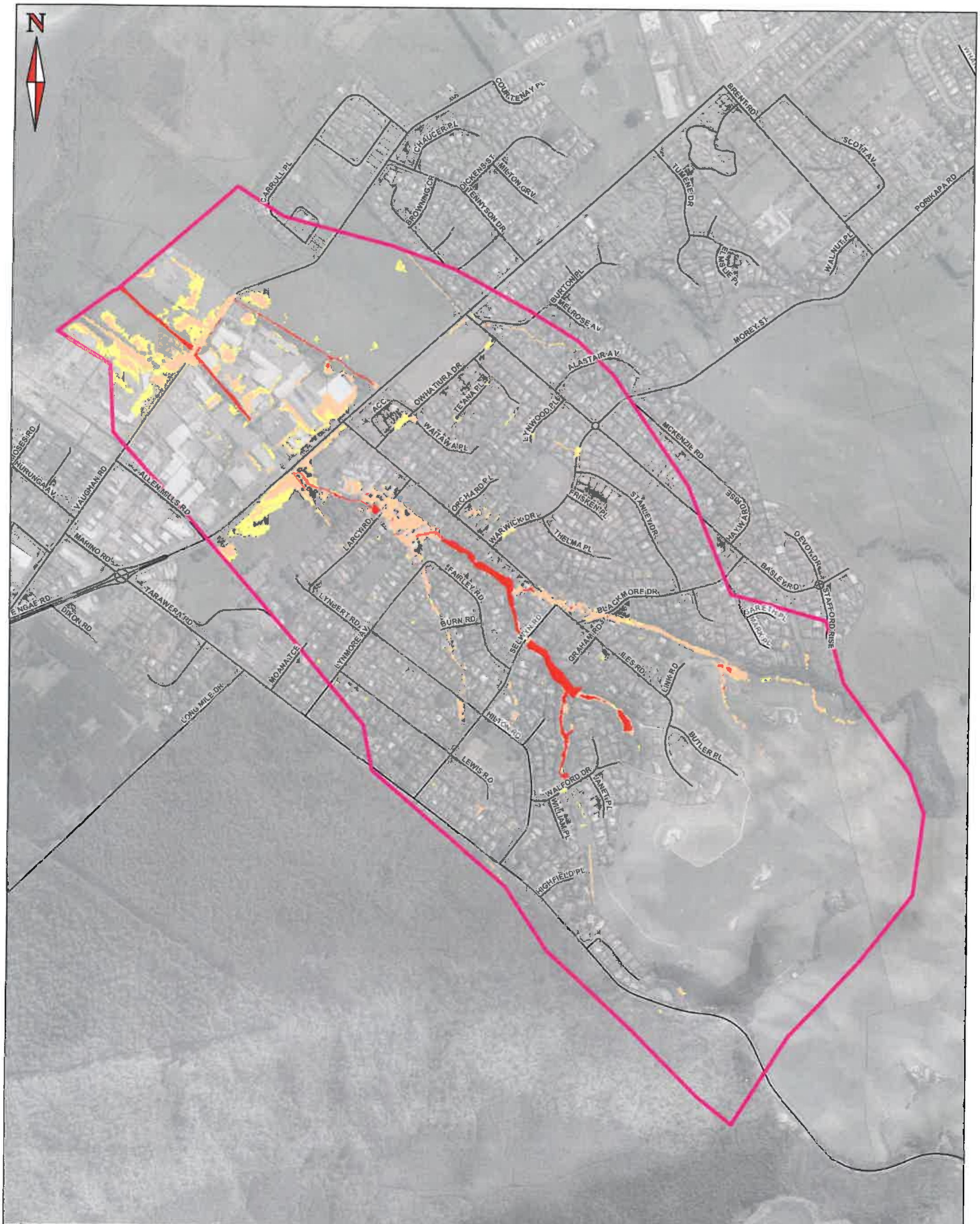
FILE REF



CONTAINS NZ TERRAIN RELIEF (TOPO50) DATA SOURCED FROM LINZ DATA SERVICE UNDER CREATIVE COMMONS ATTRIBUTION 3.0 NEW ZEALAND (CC BY 3.0 NZ)

Legend

Catchment Boundary

Parcel Boundaries

Roads

Hazard Classification

> 2 (Extreme)

1.25 to 2 (Significant)

0.75 to 1.25 (Moderate)

Original Sheet Size: A3 (V)   Projection: NZTM

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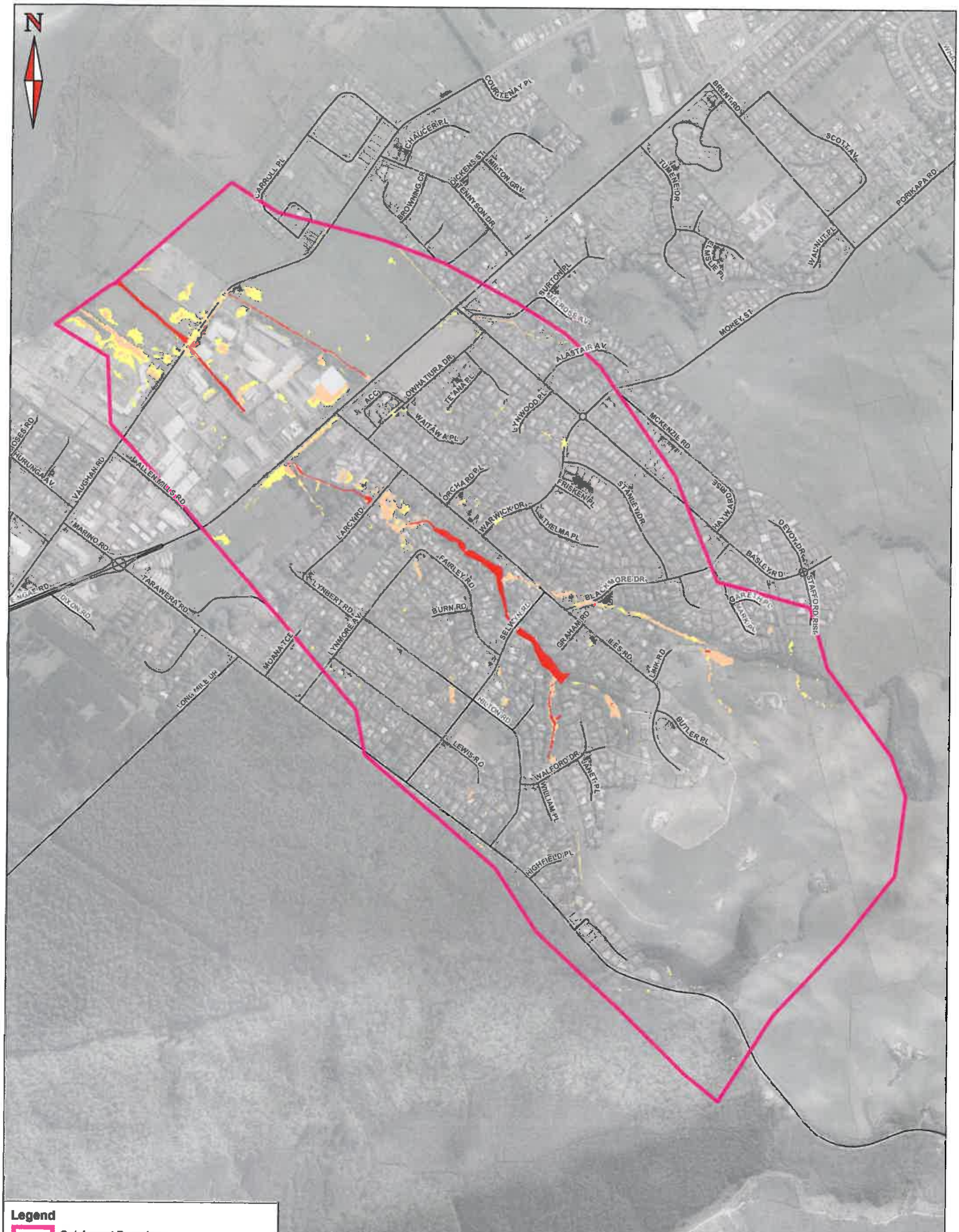
PROJECT: Rotorua Lakes Council Catchment 5 Stormwater Modelling				
DRAWN: BJS	APPROVED: LAF	REV: R1	REV DATE: 04 Aug 2016	PLAN: 2% AEP Flood Hazard Map
PROJECT NO.: 3-C1423.00	SCALE: 1:10,000 @ A3	PLAN NO: HZ-02P	SHEET NO: 1 of 1	FILE REF



Legend

- Catchment Boundary
- Parcel Boundaries
- Roads

Hazard Classification

- > 2 (Extreme)
- 1.25 to 2 (Significant)
- 0.75 to 1.25 (Moderate)

Original Sheet Size: A3 (V) Projection: NZTM

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PROJECT	Rotorua Lakes Council Catchment 5 Stormwater Modelling
PLAN	10% AEP Flood Hazard Map
FILE REF	[illegible]

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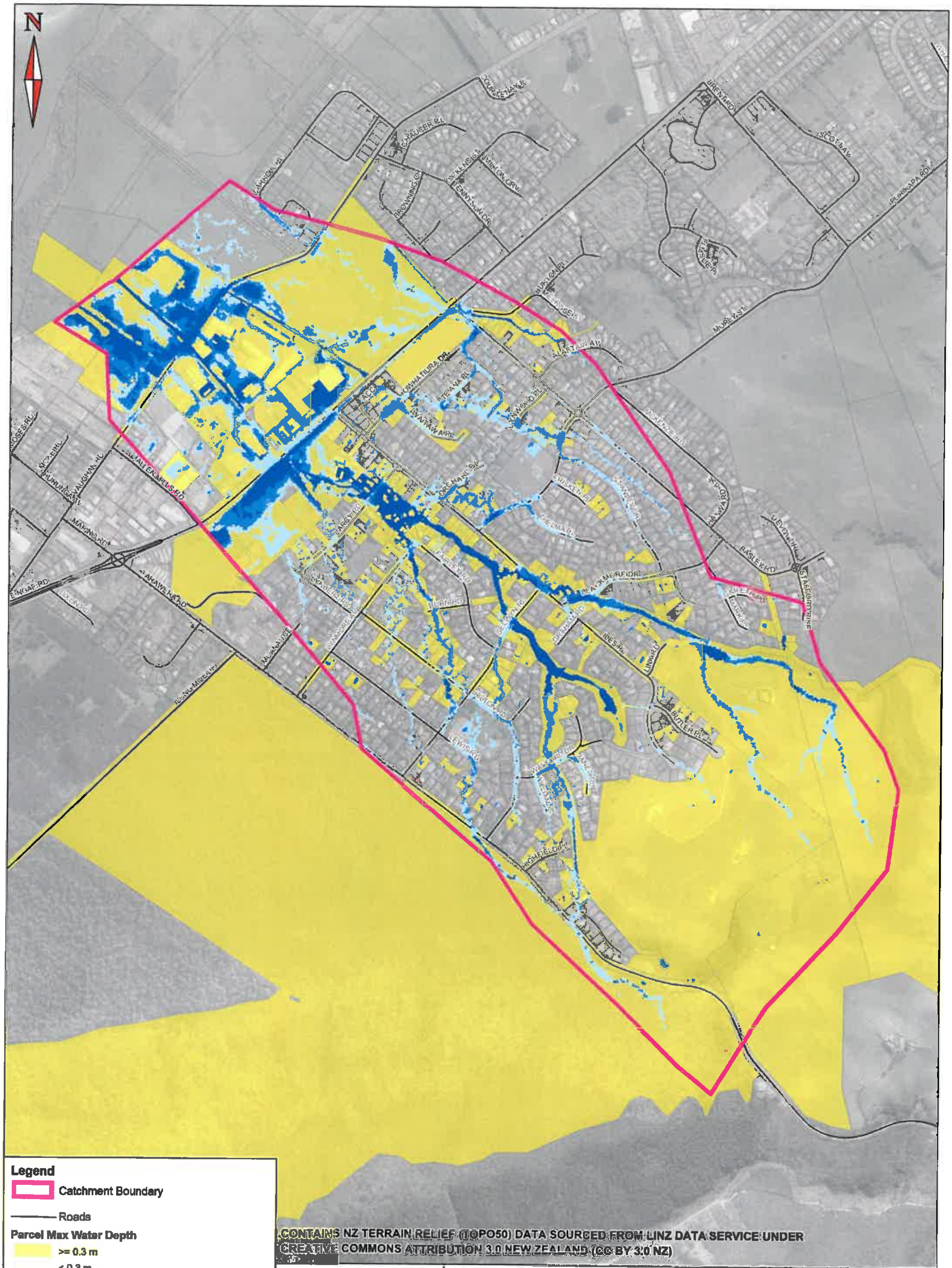
3-C1423.00	1:10,000 @ A3	HZ-10P	1 of 1



Legend

- Catchment Boundary
- Roads

Parcel Max Water Depth

- >= 0.3 m
- < 0.3 m

Flood Depth (m)

- > 0.3
- 0.15 to 0.3

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DRAWN BJS	APPROVED LAF	REV R1	REV DATE 04 Aug 2016	PROJECT Rotorua Lakes Council Catchment 5 Stormwater Modelling
PROJECT NO. 3-C1423.00	SCALE 1:10,000 @ A3	PLAN NO PC-10P	SHEET NO 1 of 1	PLAN 2% AEP Parcels >300 mm Depth

FILE REF

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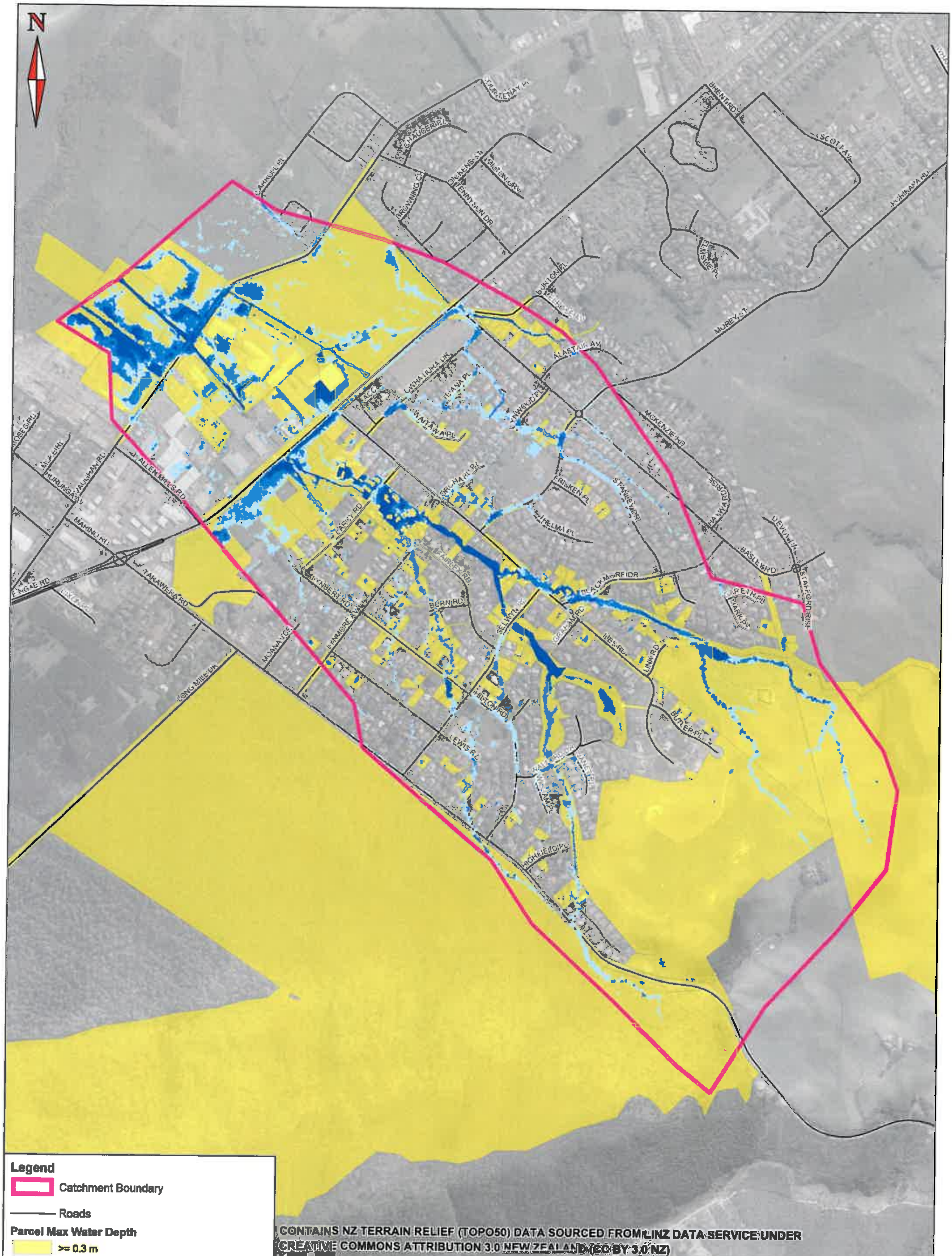

Legend

- Catchment Boundary
- Roads

Parcel Max Water Depth

- >= 0.3 m
- < 0.3 m

Flood Depth (m)

- > 0.3
- 0.15 to 0.3
- 0.05 to 0.15

Original Sheet Size: A3 (V) Projection: NZTM

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PO Box 1482
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DRAWN BJS	APPROVED LAF	REV R1	REV DATE 04 Aug 2016	PROJECT Rotorua Lakes Council Catchment 5 Stormwater Modelling
PROJECT NO. 3-C1423.00	SCALE 1:10,000 @ A3	PLAN NO PC-10P	SHEET NO 1 of 1	PLAN 10% AEP Parcels >300 mm Depth
				FILE REF [illegible]